TIGER II-PROJECT No. 18

Development of an Operational System for Monitoring and Predicting the Aquatic Plants Proliferation in Lake Victoria

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Presentation Outline

• Introduction
• Objectives
• Methodology
• Results/Analysis (MERIS, MODIS)
• Conclusions
Introduction - Background

- Lake Victoria is the largest of all African Lakes (68,000 km²)
- Produces around 1 million tones of fish p.a. providing a livelihood for around 200,000 fishermen
- Since 1980’s, it has faced environmental challenges (e.g., water hyacinth)
- Efforts to control the weed have attracted organizations like ESA, World Bank, etc.
Introduction: study area
Objectives

- To use satellite data to monitor the spatial distribution and temporal variation of the abundance of aquatic plants in Lake Victoria. It is also aimed at finding out whether there exists a correlation between these variations with some selected water quality parameters.

Specific objectives

- To obtain spectral signatures of the dominant image constituents in the lake and develop an endmember file
- To use spectral unmixing technique to classify images and obtain cover-maps for the lake
- To use the classified images to estimate the abundance of the aquatic plants in the lake
- To obtain the time series variation of aquatic plants abundance (vegetation phenology)
- To find out if there exists a correlation between the aquatic plants distribution and Chl-a and TSM water quality parameters.
Methodology

Image data requisition

Image selection

Image pre-processing

Classification

Land masking

Cloud cover evaluation

Feature extraction

Linear spectral unmixing

Arc GIS 9.3

Atmospheric corrections

Reprojection

Temporal variations

Chl-a and TSM

Rainfall

Mapping

Monitoring
Results/Analysis: Endmember extraction/Data training
Results/Analysis: Endmember extraction: Endmember spectral signatures
Results/Analysis: Classification accuracy assessment

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Results/Analysis: Mapping: Spatial distribution of vegetation
## Results/Analysis: Monitoring: Vegetated surface area

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\[ A_v = \sum_{i=0}^{1} a_i \cdot n \cdot A_p \]

- **\( A_v \)** is the surface area of vegetation in the lake
- **\( a_i \)** is the vegetation abundance value of pixel \( i \)
- **\( n \)** is the number of pixels with abundance value \( a_i \)
- **\( A_p \)** is the mean pixel dimension \((0.074 \text{ km}^2)\)
Results/Analysis: Monitoring: Vegetation phenology

Lake Victoria

Vegetated area (km²)

Acquisition date

Winam Gulf

Vegetated area (km²)

Acquisition date
Results/Analysis: Water quality analysis: Spatial distribution of Chl-a
Results/Analysis: Water quality analysis: Spatial distribution of TSM
Results/Analysis: Water quality analysis: Temporal variation of water quality parameters
Results/Analysis: Temporal variation of Rainfall (Kisumu Met. Station)
Results/Analysis: Vegetation vs. Chl-a: Testing various response periods

1 Month (± 3 days)

\[ y = 21.116x - 113.89 \]

\[ R^2 = 0.148 \]

\[ R = 0.38 \]

2 Months (± 5 days)

\[ y = 16.541x - 92.609 \]

\[ R^2 = 0.2247 \]

\[ R = 0.47 \]

3 Months (± 7 days)

\[ y = 20.593x - 120.28 \]

\[ R^2 = 0.3231 \]

\[ R = 0.57 \]

4 Months (± 10 days)

\[ y = 20.099x - 117.14 \]

\[ R^2 = 0.2611 \]

\[ R = 0.51 \]
Results/Analysis: Vegetation vs. TSM: Testing various response periods

1 Month (± 3 days)

\[ y = 9.8663x - 96.124 \]
\[ R^2 = 0.1568 \]
\[ R = 0.46 \]

2 Months (± 5 days)

\[ y = 9.7352x - 96.633 \]
\[ R^2 = 0.209 \]
\[ R = 0.46 \]

3 Months (± 7 days)

\[ y = 9.2241x - 85.338 \]
\[ R^2 = 0.1334 \]
\[ R = 0.37 \]

4 Months (± 10 days)

\[ y = 5.6194x - 39.201 \]
\[ R^2 = 0.1222 \]
\[ R = 0.35 \]
Results/Analysis: Vegetation vs. Rainfall: Testing various response periods

- **1 Month (± 3 days)**
  - \( y = 9.8663x - 96.124 \)
  - \( R^2 = 0.1568 \)
  - \( R = 0.40 \)

- **2 Months (± 5 days)**
  - \( y = 9.7352x - 96.633 \)
  - \( R^2 = 0.209 \)
  - \( R = 0.46 \)

- **3 Months (± 7 days)**
  - \( y = 9.2241x - 85.338 \)
  - \( R^2 = 0.1334 \)
  - \( R = 0.37 \)

- **4 Months (± 10 days)**
  - \( y = 5.6194x - 39.201 \)
  - \( R^2 = 0.1222 \)
  - \( R = 0.35 \)
Results/Analysis: Vegetation vs. Chl-a, TSM and Rainfall: A summary of regression results for various time delays

<table>
<thead>
<tr>
<th>Delay period (months)</th>
<th>Coefficient of Determination (R²)</th>
<th>Correlation Coefficient (R)</th>
</tr>
</thead>
<tbody>
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<td>Chl-a</td>
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<td>0.1158</td>
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<td>0.1568</td>
<td>0.148</td>
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<tr>
<td>2</td>
<td>0.209</td>
<td>0.2247</td>
</tr>
<tr>
<td>3</td>
<td>0.1334</td>
<td>0.3231</td>
</tr>
<tr>
<td>4</td>
<td>0.1222</td>
<td>0.2611</td>
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- The optimal response period for each precursor was identified as that with the highest correlation coefficient value.
- Response to TSM is highest after two months delay with R = 0.46, while response to Chl-a is highest after three months with R = 0.57. Response to rainfall is highest after three months with R = 0.67.
Results/Analysis: Vegetation abundance prediction models based on the prevailing conditions of Chl-a, TSM and Rainfall

Based on the optimum response periods of the precursors for any given day, \( n \), the following regression equations were derived to predict the vegetation abundance:

\[
A_{n+2} = 9.7 \cdot TSM_n - 96.6
\]

\[
A_{n+3} = 20.6 \cdot Chl_n - 120.3
\]

\[
A_{n+3} = 7.7 \cdot Rain_n + 36.2
\]

- \( A_{n+2} \) is the vegetation abundance in the lake two months after the specified date.
- \( A_{n+3} \) is the vegetation abundance in the lake three months after the specified date.
- \( TSM(n) \) is the mean concentration of TSM (measured in g m\(^{-3}\)).
- \( Chl(n) \) is the mean concentration of Chl-a (measured in mg m\(^{-3}\)).
- \( Rain(n) \) is the average weekly rainfall (measured in mm).
Results/Analysis: TSM vs. Chl-a: A summary of regression results for various time delays

<table>
<thead>
<tr>
<th>Delay period (months)</th>
<th>Correlation Coefficient (R)</th>
<th>Coefficient of Determination (R²)</th>
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<td>4</td>
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Regression results showed that for no delay period there is a fairly strong linear and inverse relationship between TSM and Chl-a, with R = -0.77. The relationship, however, gradually dropped in the subsequent delay periods to R = -0.28 by the fourth month.
Data - A time-series of MODIS images covering a period of **10 years** (February 2000 - January 2010) equivalent to **3650 days** of data acquisition, has been used to monitor the floating vegetation proliferation over the Winam Gulf:

- **TERRA MODIS** spectral bands 1 (620-670 nm) and 2 (841-876 nm) with a 250 meter spatial resolution to calculate the **NDVI**;
- **AQUA MODIS** spectral bands 1–4, with a 500 m spatial resolution to analyze the optical properties of the water column and to retrieve the water constituent concentrations (Chl a, TSM, CDOM);

* Source: [LAADS website](http://ladsweb.nascom.nasa.gov/data/)

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Group</th>
<th>Products</th>
<th>Start - End time</th>
<th>Collection</th>
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<th>Bands</th>
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<td>MOD02QKM Level 1B</td>
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<td></td>
<td></td>
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<td>2 – NIR 841-876</td>
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- The **rainfall** and **temperatures** recorded at the meteorological station of **Kisumu** (courtesy of the Kenya Meteorological Department);
- The **relative** **Lake Victoria height variations** computed from the TOPEX/POSEIDON (T/P), Jason-1 and Jason-2/OSTM altimeters (U.S. Department of Agriculture's Foreign Agricultural Service; [http://www.pecad.fas.usda.gov/lakes/images/lake0314.TPJO.1.txt](http://www.pecad.fas.usda.gov/lakes/images/lake0314.TPJO.1.txt)).
**Results** - The analysis highlights the trend of the floating vegetation growth within the Winam Gulf, in the time range from March 2000 to January 2010.

Before **October 2006**, the growth rate remains relatively low, with a cycle in accordance with the local climatic Conditions.

During the years **2002-2004** the weeds proliferation seems almost absent.

During **2005** and **2006** the phenomenon shows some signs of resurgence.

After **October 2006**, the proliferation of the floating vegetation exhibits an abnormal growth rate.

This event reaches its peak, in **April 2007** and ends around **January-February 2008**.
**Results** - This **abnormal proliferation** may be related to the unusual **heavy rainfall** that occurred in Kenya at the end of the 2006, swelling the rivers that flow into the Winam Gulf. The influx of fertilizer and sediments could have stimulated a new outbreak of the floating vegetation and, in particular, of the **water hyacinth**. The rainfall recorded on **November** and **December** 2006 was **346** and **284** mm respectively. This value are the **highest value** of this decade, 2.5 times larger than the ten-year average.

<table>
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<td>59,1</td>
<td>37,7</td>
<td>-</td>
<td>111,9</td>
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</table>

Monthly rainfall (mm) at the meteorological station of Kisumu (courtesy of the Kenya Meteorological Department)
Results - The lake level fluctuations could also have played a role in the weed proliferation. The early months of 2006 the water levels monitored by satellite radar altimeters (TOPEX/POSEIDON, Jason-1 and Jason-2) reached the lowest level since September 1961, about 1.3 meters lower than mean level of the last twenty years. This decrease could have caused an environmental stress on the lake ecosystem, thus creating the favourable preconditions for the occurrence of the phenomenon.
**Results** - The floating vegetation maps based on NDVI values provide an accurate temporal vision of the weeds proliferation with a time resolution of about half-week. It is possible to detect when the weeds proliferation becomes very sudden. The time sequence of this maps highlights the rapid growth of the floating weeds occurred from March to April 2007.

The weed surface **increased from about 40 to over 400 Km²** (about 33% of the Winam Gulf surface). It is also interesting to note that this rapid growth is preceded (2-3 weeks) by an increase of sparse - submerged vegetation.

![Landsat 7 image](image)

This HR image shows a very similar widespread of the floating vegetation like MODIS maps.
**Results** - The large amount of images (1370) used for this analysis provided a good statistic sample to assess the areas more affected by the weed occurrence (based on how many times the pixels were classified as floating vegetation).

This map shows the areas with the highest frequency of weeds.

They are **mainly the bays, gulfs and areas near the coastline, where water circulation is reduced.** The cause could be related to the local environmental conditions, shallow and stagnant waters that cause the increase of the nutrients and at the same time the growth and the accumulation of the floating vegetation.
Conclusions - The integrated use of MODIS imagery and other available data (satellite, rainfall, lake height variations, etc.) allowed to better understand some mechanisms that could have caused the abnormal proliferation of the floating weeds.

Availability of suitable and sufficient data is one of the greatest challenges to the proper monitoring of vegetation proliferation in Lake Victoria, owing to the large extent of the lake and the severe clouds cover in the region. In order to overcome this limitation, mosaicking of the images could be done to fill the large data gaps. For proper monitoring, the frequency of data should be at least bi-weekly.

• In the last few months of 2006, an unusual heavy rainy season removed large amounts of nutrient-rich sediments from agricultural lands into the lake ecosystem already under stress after a long water-deficit period, creating the favourable environmental conditions, for the occurrence of the weed infestation.

• The work will continue with the objective to develop an automatic system for processing in real-time the MODIS images acquired at BSC, further validate this challenging method.

• In order to develop an up-to-date decision support system, a multi-sensor approach is required.

• MODIS / MERIS data should be supported by the more precise information provided by other satellite sensors (Landsat, ASTER, CHRIS, etc.) and in particular the synergetic use of the optical and SAR data (COSMO-Sky-Med).
L. Fusilli, M. O. Collins, G. Laneve, A. Palombo, S. Pignatti and F. Santini, October 2011, Assessment of the abnormal growth of floating macrophytes in Winam Gulf (Kenya) by using MODIS imagery time series.

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The End.

Thanks for your attention.